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Enhancing the Expressiveness of the Bunge-Wand-Weber Ontology

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ABSTRACT

In practical terms, conceptual modeling is at the core of systems analysis and design. The plurality of modeling methods available has however been regarded as detrimental, and as a strong indication that a common view or theoretical grounding of modeling is wanting. This theoretical foundation must universally address all potential matters to be represented in a model, which consequently suggested ontology as the point of departure for theory development. The Bunge–Wand–Weber (BWW) ontology has become a widely accepted modeling theory. Its application has simultaneously led to the recognition that, although suitable as a meta-model, the BWW ontology needs to be enhanced regarding its expressiveness in empirical domains. In this paper, a first step in this direction has been made by revisiting BUNGE's ontology, and by proposing the integration of a "hierarchy of systems" in the BWW ontology for accommodating domain specific conceptualizations.

Keywords

Conceptual modeling, modeling grammars, ontological foundations, Bunge–Wand–Weber ontology.

INTRODUCTION

Conceptual modeling is one of the most fundamental means for information systems development. Understanding rational and methodical information systems development as a process comprising successive phases, BOEHM (1981) showed that the cost of fixing errors increase exponentially over the time between making an error and its subsequent fixing in later phases. Hence, a strong economical motivation is given for avoiding errors especially in the earliest phase of the information systems development process—the phase of requirements engineering.

In requirements engineering we have come to use conceptual modeling methods for multiple purposes, such as design, communication, and documentation (e.g., Kung and Sølvberg, 1986). Correspondingly, methods for conceptual modeling in requirements engineering abound, and "yet another modeling approach" (YAMA) (Oei, Van Hemmen, Falkenberg, and Brinkkemper, 1982) is frequently being added. It is acknowledged that the untamed proliferation of conceptual modeling methods is due to the general lack of theoretical foundations of conceptual modeling, even if some attempts have been undertaken in order to overcome this highly undesirable situation (e.g., Wand, Monarchi, Parsons and Woo, 1995; Siau and Rossi, 1998).

One category of approaches towards the development of theoretical foundations of conceptual modeling draws on ontology. Yet there is an important distinction to be made: While some of the ontological approaches are based on the understanding of ontology as "a specification of some conceptualization" (e.g., Guizzardi, Herre and Wagner, 2002), other approaches are based on an understanding of ontology in philosophical terms (e.g., Milton and Kazmierczak, 2004). In this paper we are concerned solely with the latter approaches, especially with an approach that can well be considered as the most prominent and most developed in information systems—the so-called Bunge–Wand–Weber (BWW) ontology (e.g., Wand and Weber, 1988). The BWW ontology is based on the scientific and dialectical-materialist ontology developed by MARIO BUNGE (1977; 1979).

The development of the BWW ontology began in 1986 (e.g., Weber, 1997) and it gained—after a number of publications addressing fundamental aspects of this approach (e.g., Wand and Weber, 1988; 1990)—increasing popularity in the information systems research arena. It has been widely applied in contexts such as comparison of information systems analysis and design grammars (e.g., Green, 1996), ontological evaluation of modeling grammars (e.g., Rohde, 1995; Davies, Rosemann and Green, 2004) and of reference models (e.g., Fettke and Loos, 2003), information systems interoperability (e.g., Green and Rosemann, 2002), development of theoretical foundations for data quality (e.g., Wand and Wang, 1996), for modeling languages (e.g., Opdahl and Henderson-Sellers, 2001), and for method engineering (e.g., Wand, 1996) as well as requirements engineering for commercial-off-the-shelf software (e.g., Soffer, Golany, Dori and Wand, 2001) and alignment in enterprise systems implementations (e.g., Rosemann, Vessey, and Weber, 2004).

Yet in contrast to the application of the BWW ontology to more formal phenomena such as modeling grammars, it has been the application of the BWW ontology to non-formalized phenomena such as enterprise systems that revealed some limitations of the BWW ontology. For example, OPDAHL and HENDERSON-SELLERS (2004) recognized that the BWW ontology seems to be well-suited for the modeling of concrete things such as materials, but not for the modeling of, e.g., social constructs. The lack of methodical support for the application of the BWW ontology has been recognized by ROSEMANN, GREEN and INDULSKA (2002). And the non-intuitive understandability of the BWW ontology has been answered with the development of a meta-model of constructs of the BWW ontology (Rosemann and Green, 2002).

Despite the efforts already made to improve the applicability of the BWW ontology to non-formalized domains such as business organizations, we believe that a sustainable and theoretical sound enhancement of the expressiveness of the BWW ontology is still missing. To address this issue, we propose an enhancement of the BWW ontology, drawing on BUNGE's concept of an ontological hierarchy of systems (Bunge, 1979). The integration of this concept in the BWW ontology eventually increases the expressiveness of the BWW ontology, especially in empirical (hence non-formalized) domains. Thus, our paper is structured as follows:

First, we recount the core constructs of the BWW ontology, as they have been extracted from BUNGE's work. Second, we present BUNGE's semantics and how it is applicable to formal languages. Third, we argue that for the sake of consistency and theoretical soundness, salient concepts of BUNGE's semantics should become part of the BWW ontology. Finally, we introduce the BUNGE's concept of a "hierarchy of ontologically distinct systems" and illustrate how the integration of this concept into the BWW ontology substantially enhances its expressiveness.

THE BUNGE–WAND–WEBER ONTOLOGY

The development of the BWW ontology has its roots in fundamental problems of conceptual modeling. WAND and WEBER recognized that the quality of conceptual models is always dependent on the correspondence between the model and what the model is about. They assumed that this correspondence will be greatly supported by using a conceptual modeling language that provides the constructs that are (nearly) the same as the concepts people use to structure their conceptions of the world (Weber, 1997). Approached by WEBER, MATTESSICH—an accounting researcher and philosopher of science (e.g., Mattessich, 1978)—pointed to the work of BUNGE, of which he believed that it would eventually provide WAND and WEBER with the concepts they were looking for.

Equipped with a comprehensive work on scientific ontology, WAND and WEBER set out to develop a "formal foundation for modeling information systems" (Wand and Weber, 1990a). In doing so, they adapted a number of notions conceived by BUNGE, and developed a rather formal ontology that later became known as "Bunge–Wand–Weber ontology." WAND and WEBER also adopted the formalism used by BUNGE for the formalization of ontological notions.

WAND and WEBER admit that the adaptation of BUNGE'S ontology is to a certain extent reductionistic, meaning that not all ontological concepts conceived by BUNGE are represented in the BWW ontology. We especially believe that the neglect of the concept of a hierarchy of systems is responsible for some of the difficulties that arise when the BWW ontology is applied to empirical systems. The reasoning underlying this claim may be illustrated by depicting some constructs of the BWW ontology:

- *Thing*: "The world is made of things that have properties" (Wand and Weber, 1989).
- *Composite Thing*: "A composite thing may be made up of other things (composite or primitive)" (Wand and Weber, 1995).
- *Conceivable State*: "The set of all states that the thing may ever assume" (Wand and Weber, 1995).
- *Transformation of a Thing*: "A mapping from a domain comprising states to a co-domain comprising states" (Wand and Weber, 1995).
- *Stable State of a Thing*: "A state in which a thing, subsystem or system will remain unless forced to change by virtue of the action of a thing in the environment (an external event)" (Wand and Weber, 1995).
- *Property*: "We know about things in the world via their properties (Weber, 1997).
- *Mutual Property*: "A property that is meaningful only in the context of two or more things" (Wand and Weber, 1995).

- *System*: "A set of things will be called a system, if, for any partitioning of the set, interactions exist among things in any two subsets" (Wand and Weber, 1989).
- *Subsystem*: "A system whose composition and structure are subsets of the composition and structure of another system" (Wand and Weber, 1995).
- *Natural Law*: "Natural laws are established by nature" (Weber, 1997).

From the above depiction of a select number of ontological constructs it becomes obvious that the abstract characterizations of those constructs do not lend themselves easily to a mapping of empirical systems such as business organizations. When the BWW ontology should be of use in empirical domains it needs to provide a means of rendering its constructs meaningful in each empirical domain of application.

ON SEMANTICS AND THE EXPRESSIVENESS OF THE BUNGE–WAND–WEBER ONTOLOGY

The dealing with issues of expressiveness belongs to the realm of Semantics, a discipline that BUNGE has reflected upon at length (Bunge, 1974; 1974a). Since it cannot be in the scope of this paper to review BUNGE's entire work on Semantics, we restrict ourselves to the presentation of just those aspects that we deem most relevant for the given purpose—the enhancement of the expressiveness of the BWW ontology.

BUNGE theorizes about semantic issues with explicit reference to ontology (Bunge, 1974, p. 26):

(i) Every *object* is either a factual item […] or a construct […] and none is both.

(ii) Every *factual* object is either linguistic or extralinguistic and none is both.

(iii) Every *linguistic object* is either a term […] or an expression […] or a whole language.

(iv) Every *construct* is either a predicate or a propositional function or a proposition or a set of either […].

These statements make it clear that linguistic objects, such as terms or whole languages, are not conceptual but rather something factual (i.e., consisting of things). As depicted in Figure 1, BUNGE distinguishes between "marks," "constructs," and "objects." Marks are understood to be physical signs (symbols), constructs to be concepts (fictional objects), and objects to be factual objects (e.g., things).

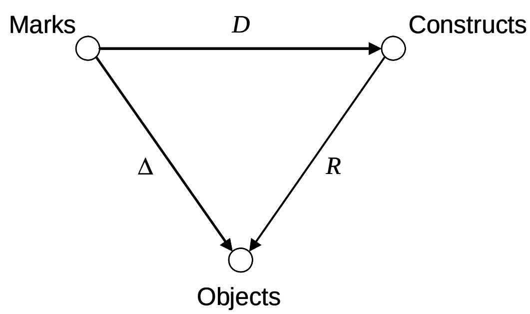

Figure 1. 'Semiotic Triangle' according to BUNGE (1974)

Hence, marks are physical signs that designate (*D*) concepts (constructs), and concepts refer (*R*) to objects. If both a designation (*D*) and a reference (*R*) are given, then a denotation (Δ) can be constructed as the relational product of *D* and *R* (Bunge, 1974, pp. 42–43).

Applied to conceptual modeling languages, the 'semiotic triangle'—according to BUNGE—can provide useful insights into issues of expressiveness of the modeling languages. First, we recognize the modeling language as consisting of factual objects, i.e., linguistic objects, i.e., marks or symbols. Without a designation (*D*) the symbols are meaningless. Symbols used in a conceptual modeling language need to designate concepts in order to become meaningful. Second, concepts themselves become only "factual meaningful" if they refer (*R*) to factual objects. Otherwise concepts are fictions (e.g., unicorn). In the latter case, the denotation (Δ) coincides with the designation (D). Hence, if a conceptual modeling language is applied in an empirical domain, the symbols of the language become only meaningful with respect to this domain if the symbols designate concepts that refer to factual objects of the domain. Only then can we say that a term denotes a certain factual object. If this premise is not met, the symbol denotes and designates a fictional object, i.e., a concept.

Applied to the BWW ontology, the 'semiotic triangle'—according to BUNGE—helps to identify the weakness of the BWW ontology's expressiveness. Being a formal theory rather than an empirical theory, the 'constructs' (symbols) of the BWW ontology refer only to concepts, not to factual objects. This explains the difficulties that arise when the BWW ontology is applied in empirical domains. The BWW ontology does not and cannot provide for the reference of concepts to factual objects. The BWW ontology only provides the terms (marks), the concepts, and the respective designation rules. In other words, the BWW ontology is a formalism, and a "*formalism* is by itself neutral with respect to matters of fact. So, unless the formalism is 'read' in factual terms, it will 'say' nothing about reality" (Bunge, 1974, p. 104).

How do we "read" the formalism BWW ontology in factual terms? BUNGE writes: "The factual interpretation of a theory is superimposed on a mathematical framework with a definite mathematical meaning and is determined by two disjoint sets of semantic rules. One is formed by the *denotation rules* or symbol-thing correspondences identifying the referents of the theory. This set constitutes […] the 'dictionary' of the theory. The other is the set of *semantic assumptions* or function property correspondences. Whereas the former point to and baptize the referents of the theory, the semantic assumptions link constructs to factual items by indicating the traits of things that the constructs are supposed, rightly or wrongly to represent" (Bunge, 1974, p. 105).

Hence, in order to turn some statements based on the formalism BWW ontology into some model of an empirical domain (or of a part of an empirical domain) we have to provide both a set of denotation rules and a set of semantic assumptions. It is evident that the provision of denotation rules is somewhat easier to accomplish than the provision of the semantic assumptions. Yet the semantic assumptions are of utmost importance for the enhancement of the expressiveness of the BWW ontology, since only the semantic assumptions provide "the traits of things the constructs are supposed […] to represent." Only the set of semantic assumptions provides the means for the identification of the factual objects that are to be represented by means of the BWW ontology (or any other formalism).

Intuitively, it seems to be reasonable to identify the notion of semantic assumptions with the more traditional semiotic notion of meaning. Yet nothing could be farther from the truth. For BUNGE, semantic assumptions are philosophical in nature, comprising both ontological and epistemological assumptions. Hence, "semantic assumptions commit us to and what their philosophical underpinnings are. And we must demand that every semantic assumption, far from being accepted by authority, be *testable* both conceptually and empirically, namely thus:

(i) A semantic assumption should *fit the structure* of the concept concerned and it should not violate any of the basic formulas in which the construct occurs. Checking this condition is of course a matter of pencil and paper: it is a conceptual test.

(ii) The construct involved in a semantic assumption should in fact describe what it is assumed to represent. Checking this condition calls for *empirical tests* of some of the formulas interpreted by the semantic assumptions" (Bunge, 1974, p. 110).

Thus BUNGE's theorizing on Semantics not only provides us with insights regarding theoretical semantic aspects of conceptual modeling languages and formal ontologies but also with methodical guidelines that support the creation of formally and semantically correct (ontological) models.

A review of a large part of the body of literature that is concerned with the development and application of the BWW ontology reveals that the semantic aspects of the BWW ontology have so far been ignored completely. We are not aware of any publication that addresses semantic issues of the BWW ontology. This finding is somewhat surprising since BUNGE explicitly deals with the semantic issues of modeling (e.g., Bunge, 1974; 1974a).

ENHANCING THE EXPRESSIVENESS OF THE BUNGE–WAND–WEBER ONTOLOGY

Aiming at the application of the BWW ontology in the context of enterprise modeling, OPDAHL and HENDERSON-SELLERS (2004) propose a template for the definition of enterprise modeling constructs that is based on the formalism provided by the BWW ontology. They motivate their approach as follows: "The main idea is to provide a standard way of defining modelling constructs in terms of the BWW model, in order to make the definitions cohesive and, thus, learnable, understandable and as directly comparable to one another as possible. Another important idea is to provide a way of defining modelling constructs not only generally, in terms of whether they represent 'classes', 'properties' or other ontological categories, but also in terms of which classes and/or properties they represent, in order to make the definitions more clearly and precisely related to the enterprise" (Opdahl and Henderson-Sellers, 2004).

OPDAHL and HENDERSON-SELLERS not only address practical semantic issues of the BWW ontology, but also issues of usability. Yet they do not consider a modification of the BWW ontology, rather they introduce an intermediate 'layer' between the BWW ontology and the actual model of an enterprise. Hence, they use the formalism BWW ontology to specify less abstract constructs, which is only possible through the implicit 'integration' of knowledge about enterprises. In terms of BUNGE, the template is created through a formalization of a factual theory. This does not result in an enhancement of the expressiveness of the BWW ontology, but in a formalized factual theory. Nevertheless, the similarity to BUNGE's conceptualization of 'reading' a formalism in terms of a factual theory is evident. The limitations of the approach proposed by OPDAHL and HENDERSON-SELLERS are obvious as well: the concept of a template leads to static conceptual structures for rather narrow domains. The universality that is an essential feature of the BWW ontology gets lost.

As indicated by the preceding section, our proposed enhancement of the expressiveness of the BWW ontology rests with the semantic theory conceived by BUNGE (1974; 1974a). In contrast to the approach proposed by OPDAHL and HENDERSON-SELLERS (2004), we do not attempt to find a solution to the issue of expressiveness that is in conflict with BUNGE's ontology and his semantic theory. Rather we draw on the concept of the hierarchy of systems (Bunge, 1979).

It has already been recognized that BUNGE's concept of the hierarchy of systems is not reflected in the BWW ontology, even if the BWW ontology includes concepts such as super-sub-system hierarchies and emergent properties (Rosemann, Vessey, Weber and Wyssusek, 2004). Yet BUNGE's concept of the hierarchy of systems is not just a concept that allows the hierarchical concatenation of super-sub-system hierarchies. Rather it describes a hierarchy of distinct ontological levels. These levels are 'separated' by qualitative leaps that are due to the emergence of certain systemic properties. In BUNGE's words: "The intuitive idea [of ontological distinct levels] is simple: the things at any given level are composed of things belonging to preceding levels. Thus biospheres are composed of ecosystems, which are composed of populations, which are composed of organisms, which are composed of organs, which are composed of cells, which are composed of organelles, which are composed of molecules, which are composed of atoms, which are composed of so-called elementary particles" (Bunge, 1979). A depiction of BUNGE's concept of the hierarchy of systems is given in Figure 2.

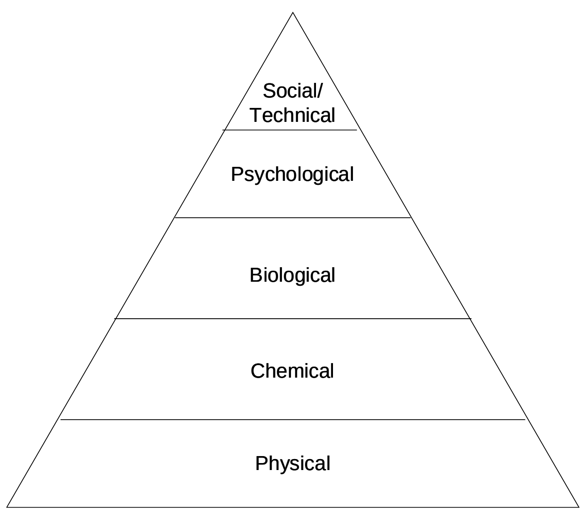

Figure 2. Hierarchy of Systems (BUNGE, 1979)

The essential consequence of the concept of the hierarchy of systems is thus that at each level we need specific concepts to account for the emergent properties that give the respective level its identity. With respect to the BWW ontology this means that its constructs assume a different meaning at each different level. Hence a "thing" at the physical level assumes a different meaning than at, e.g., the socio-technical level.

We can now return to BUNGE's theorizing on semantics. With the formalism BWW ontology and the concept of the hierarchy of systems given, we are able to integrate both. Since the formalism BWW ontology is lacking any semantic assumptions, we need factual theories that provide us with the necessary semantic assumptions that give the formalism a meaning with respect to empirical domains. Yet how do we identify the factual theory that will serve our purpose? We identify such theories by drawing on the concept of the hierarchy of systems. This concept basically mirrors the disciplinary subdivision of the sciences. If we are concerned with modeling, e.g., biological phenomena, we do not need a formalism specific to this domain. What we need is a general formalism, such as the BWW ontology, and a factual theory, e.g., the theory of evolution, that provides us with the semantic assumptions about the domain of biological phenomena.

Examples of the integration of a general ontological theory and the concept of the hierarchy of systems are provided by BUNGE (1979), e.g., when he theorizes the notion of a "human society." On pp. 6–7 he introduces the general ontological notion of a concrete system; on pp. 189–190 he uses factual social theory, hence an empirical theory extant on the socio-technical level of the hierarchy of systems, in order to provide semantic assumptions that give meaning to the symbols used in the formalization of the general ontological notion of a concrete system. Thus we finally refer the reader interested in deepening her/his understanding of the importance of the relation between general ontology and factual theory for ontology-based conceptual modeling not only to BUNGE's works on semantics (1974; 1974a) but also to his largely neglected Ontology II (1979).

Hopefully we have illustrated that a careful reconsideration of BUNGE's work can help to overcome—in a theoretically sound way—some obstacles that hinder the application of the BWW ontology in empirical (hence non-formal) domains. We also hope to have convincingly shown that a heuristic and intuitive approach, exemplified by the one proposed by OPDAHL and HENDERSON-SELLERS (2004), has—despite it pragmatic value—certainly its limitations due to (1) the constraints that it imposes upon the generality of the BWW ontology and (2) its lack of theoretical grounding.

CONCLUSION

The preceding discussion has sought to address some of the concerns that have been voiced regarding a further development of the Bunge–Wand–Weber ontology. While the expressiveness of that ontology has been augmented, there is still the need of methodical guidance as well as the need to better cater for important aspects of the world that have to be modeled for information systems, i.e., social constructs in general and business phenomena in particular. This means enhancing the expressiveness of that ontology regarding empirical domains. Since the BWW ontology up until now has been regarded as a formal system, it is necessary that this enhancement must deal with problems of semantics, which have not been considered as yet. In information systems, where conceptual models are not only means of design, but function as constructs for communication and documentation, the significance of a sound semantics of modeling cannot be overestimated.

We claim that by confronting these demands, it has been worthwhile to revisit BUNGE's ontology in search of a theoretically founded semantics for conceptual modeling. Firstly, this has confirmed the need for a semantic extension: BUNGE himself already stressed that formalisms as such do not have any meaning, and hence no theoretical or practical relevance whatsoever. Pure formalisms have to be set in relation to a theory that is based on empirical knowledge; there is a dialectical nexus between the two, in that formalisms contribute to theory formation and conversely need to be validated against empirical-theoretical insights. Secondly, the core construct that relates formal ontology with empirical theory has been identified: this is the concept of the ontological hierarchy of systems. According to the hierarchy of systems, formal constructs then obtain differing connotations (e.g., "thing" at the physical level of the hierarchy has a different meaning than "thing" at the socio-technical level). In the sense of BUNGE's dialectic, these qualitative leaps are conceptualized as the actualization of emergent properties, which affect the aggregation of matter into a higher ontological level.

These insights warrant a further development of the BWW ontology towards semantics, which is theoretically sound, since it is reliant on a comprehensive philosophical system. That development is guided by a systemic representation of the world that should be at least as easily communicable to scholars as BUNGE's formalism used to be. An even closer relation to 'real world' knowledge is possible through BUNGE's ontology as well, since he has identified further sublevels within the ontological levels, which could be treated as analogous to domain ontologies.

We believe that this semantic extension, if performed with the adequate rigor, will pave the way for a wide applicability of the BWW not only in terms of its inherent scope, but foremost in terms of its comprehensibility and its acceptance in the community of modelers.

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